CHERNOBYL FACT FILE

A Guide for Nuclear Industry Professionals

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NucNet: The Nuclear Communications Network

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Introduction

Few technical subjects raise as much controversy as nuclear energy and few nuclear subjects are as emotive as the disaster at Chernobyl in what was then the Soviet Union (now Ukraine) in April 1986. The word “Chernobyl” conjures up images of environmental catastrophe and serious long-term human health consequences.

But who knows what really happened? A combination of rumour and the complex nature of scientific evidence surrounding Chernobyl can make it difficult to establish fact from fiction. The picture is complicated further by contradictory media reports.

On some questions, there are no unequivocal answers. Early speculation was that radiation exposure would claim tens of thousands of lives. Yet as of the end of 2010, fewer than 50 deaths had been directly attributed to it. According to three branches of the United Nations – the World Health Organisation (WHO), the United Nations Scientific Committee on the Effects of Atomic Radiation (Unscear), and the International Atomic Energy Agency (IAEA) – poverty, mental health problems and lifestyle diseases now common in the former Soviet Union pose a greater threat to local communities than radiation exposure.

The accident at Chernobyl distorted the arguments both for and against nuclear power. As the arguments became distorted, so did the popular view of what had gone wrong and what happened in the accident's aftermath.

This is a crucial time for the nuclear energy industry, with renewed interest worldwide in building new reactors to deal with climate change and security of supply, and the aftermath and lessons to be learned from the serious accident at the Fukushima-Daiichi nuclear plant in Japan in March 2011.

The IAEA says more than 60 countries – mostly in the developing world – have told it they are interested in starting nuclear power programmes. Among countries engaged in new-build programmes are: Argentina, Brazil, Bulgaria, China, Finland, France, India, Iran, Japan, Pakistan, Russia, Slovakia, South Korea, Ukraine, the United Arab Emirates, the United Kingdom and the United States.

Twenty-five years have passed since Chernobyl. The technology of nuclear energy has changed dramatically. The Chernobyl accident significantly slowed down nuclear developments throughout the Soviet bloc. The construction of new plants was stopped and plans put on hold in the face of environmental protests, local authority resistance, and serious economic problems. But public hostility to nuclear power abated, allowing an ambitious new programme of civil nuclear power development to be drawn up. Worldwide, because of growing concern about energy security and global warming, nuclear energy is back at the top of the political agenda – and back in the media.

This Chernobyl Fact File, published by the Brussels-based nuclear energy communications network NucNet, is designed to help nuclear communications professionals and journalists covering Chernobyl and nuclear energy in general, understand the reasons behind what happened and for the contradictions that have arisen. It concentrates on the facts of

Chernobyl. Where the facts cannot be established, it takes as its sources scientific evidence such as the 2005 Chernobyl Forum report[*] on health consequences, the Nuclear Energy

Agency's 2002 Assessment of Radiological and Health Impacts[†], and the 2011 Unscear report on the health effects due to radiation from the Chernobyl accident[‡].

Each section of the Chernobyl Fact File deals with an important aspect of the accident and its aftermath, including how it happened, why it happened and the steps that were taken to make sure it could not happen again. The events leading up to and following the accident are described and explained. Chernobyl myths are dispelled, the reasons for and the repercussions of the accident clarified.

The information in this document is directed at communicators, but is equally as pertinent to researchers, students, nuclear professionals and politicians.

Summary

The Chernobyl nuclear power plant had four RBMK reactor units. These are light-water graphite reactors. The accident on 26 April 1986 was in the fourth unit.

RBMK is an acronym for *reactor Bolshoi moshchnosti kanalniy* (Russian for “high-power channel reactor”), a type of reactor with individual fuel channels. It uses ordinary water as its coolant and graphite as its moderator. Moderator is the medium that reduces the speed of fast neutrons from nuclear fission, thereby turning them into thermal neutrons capable of sustaining a nuclear chain reaction involving uranium-235. The combination of graphite moderator and water coolant is found in no other type of nuclear reactor.

The RBMK was never built outside the former Soviet Union and had certain design characteristics that would have prevented it receiving a licence elsewhere. Most notably, it had characteristics which made it prone to power surges. And it had no full containment structure.

The accident at Chernobyl was caused when the reactor's operating crew switched off safety systems so they could carry out a test. A violent explosion blew off the 1000-tonne sealing cap on the reactor top. A second explosion threw out fragments of burning fuel and graphite from the core and allowed air to rush in, causing the graphite moderator to burst into flames.

[*] Chernobyl’s Legacy: Health, Environmental and Socioeconomic Impacts (Chernobyl Forum, September 2005).

[†] Assessment of Radiological and Health Impacts – 2002 Update of Chernobyl: Ten Years On (Nuclear Energy Agency).

[‡] Health Effects Due to Radiation From the Chernobyl Accident – Sources and Effects of Ionizing Radiation Unscear 2008, Volume 2, Annex (United Nations Scientific Committee on the Effects of Atomic Radiation, February 2011).

The initial explosion resulted in the deaths of two workers. Twenty-eight of the firemen and emergency clean-up workers died within three months of acute radiation sickness and one of cardiac arrest.

Long-term health effects have occurred since 1986 and may also occur in the future. A 2005 report published by the IAEA said up to 4000 people could eventually die of radiation exposure from the accident. It also said public health effects have not been nearly as substantial as had at first been feared.

As of end-2010, fewer than 50 deaths had been attributed to radiation from the accident, almost all being highly exposed rescue workers, many who died within months of the accident, but others who died as late as 2006.

All four reactors at Chernobyl have been shut down and the plant is no longer operational. The last reactor, unit 3, was shut down on 15 December 2000. Decommissioning is continuing.

There are 15 RBMK reactors in operation today, all in Russia. All these RBMK reactors have undergone modifications to eliminate the deficiencies that caused the Chernobyl accident. Other RBMK reactors, including two in Lithuania, have been shut down as a condition of this country's entry into the European Union.

In 1986, a shelter was built to enclose the remnants of the destroyed Chernobyl reactor number four. The shelter, initially called a "sarcophagus", was hurriedly built in seven months and has deteriorated. To reduce the risk of collapse the roof and the western wall were successfully stabilised from 2004 to 2008. Inside the shelter, the ventilation stack got new structural supports. The stabilisation was finished on time and within the cost estimate of about US$50 million.

A conceptual design of a new arch-shaped structure, known as the New Safe Confinement (NSC) was decided in 2001 and the safety document approved in 2008. The main orders for steel and crane were placed in 2010. On-site construction is scheduled to start in late 2011.

With a 100-year design life, this huge structure will be constructed away from the sarcophagus to reduce radiation exposure to workers. When complete, it will be slid over the sarcophagus in a single day. This will isolate the sarcophagus from the weather and outside environment, and provide safe conditions for future deconstruction work that will take place inside the shelter.

The Chernobyl Shelter Fund, managed by the European Bank for Reconstruction and Development (EBRD), was set up in 1997 to make the sarcophagus stable and environmentally safe, clean up the site, build intermediate storage facilities for radioactive waste and fuel, and build the NSC. The overall cost of the Shelter Implementation Plan is close to €1.6 billion. Twenty-three countries, the European Union and EBRD shareholders will share the costs.[§]

[§] Chernobyl 25 Years on: New Safe Confinement and Spent Fuel Facility (European Bank for Reconstruction and Development, London, 14 December 2010)

The Accident

In the early hours of Saturday 26 April 1986, the world's worst nuclear power accident occurred at the Chernobyl nuclear power plant in the former USSR, now Ukraine, 130 kilometres north of Kiev.

The accident was the result of a flawed Soviet reactor design coupled with mistakes made by the plant operators within a system where training was minimal and feedback of experience unknown. These failings, in turn, were a direct consequence of Cold War isolation and the resulting lack of a rigorous safety culture.

Reactor number four, an RBMK unit of 925 megawatts (MW) was to be shut down for routine maintenance and it was decided to take advantage of this to run a test. Ironically, the test was designed to improve safety. The reactor's cooling pumps relied on electrical power, so the operators wanted to determine whether, in the event of a loss of power, the kinetic energy of the slowing turbo-generator could provide enough electrical power to operate the emergency equipment and the core cooling water circulating pumps until the diesel emergency power supply became operative.

To reduce cooling requirements, the reactor was to be run at low power, despite the fact that RBMK reactors were known to be unstable at low power settings. The test had been attempted on two previous occasions but never completed.

The reactor's power was reduced to half power and one of the two turbo-generators powered by the reactor was disconnected. The reactor's emergency cooling system was deliberately disabled, because operators didn't want it cutting in when the main pumps slowed. At this point, grid controllers asked for the test to be delayed due to system requirements. The reactor ran for more than nine hours in this condition until permission was given to continue reducing power for the test to proceed. The power should have been held at the test level of 700 MW to 1,000 MW, but the automatic control was incorrectly set and power fell to 39 MW, allowing concentrations of the neutron-absorbing fission product xenon to build up.

This, together with the fact that six main cooling pumps were operating and water flow was excessive, significantly decreased reactivity, making it difficult for the operator to restore power. Eventually, the operator managed to stabilise the power at 200 MW, but was unable to increase it further due to loss of reactivity. This power level was well below that required, but the decision was taken to go ahead with the test.

Two further standby cooling water pumps were started, leading to an increase in water flow beyond operating limits. This caused a reduction in steam bubbles in the cooling system, reducing reactivity still further. Control rods – which are used in nuclear reactors to control the rate of fission – were withdrawn beyond prescribed limits in an attempt to increase reactivity.

At one point, only six to eight control rods were being used. According to procedure, at least 30 were required to maintain control. If there were fewer than 30, the reactor should have been shut down.

Operators continued the test, despite knowing that about 20 seconds would be required to lower all the control rods and shut down the reactor in the event of a power surge. To keep the test going, the protection system that would have tripped the reactor if limits were exceeded was disconnected. The test was started by closing the steam supply to the turbo generator.

As the turbine ran down, the amount of cooling water being provided to the reactor decreased and steam was produced at a rapid rate. The reactor's positive void coefficient – the increase in the number of fission reactions and consequently of power production when there are voids (e.g. steam bubbles) instead of water in the fuel channels – meant the reactor produced more power and even more steam and hence more voids in the fuel channels: a typical "runaway" process.

At 01:23 local time on 26 April, there was a sudden and unexpected power surge. Reactor power increased exponentially, up to an estimated 100 times nominal. The control rods could not be fully re-inserted in time. Their design simply did not allow an accelerated insertion. What's more, their design meant that initial displacement of water as they were lowered into the channels could exacerbate the situation. The fuel overheated and some of the fuel channels ruptured.

The resulting explosion, thought to be caused mainly by steam pressure and chemical reaction with the exposed fuel, blew the 1000-tonne sealing cap on the reactor clear of the core. A second explosion threw out burning fuel and graphite from the core and allowed air to rush in, causing the graphite moderator to burst into flames. The exact cause of the second explosion remains unknown, but it is thought that hydrogen may have played a part.

Determining the causes of the accident was not easy, because there was no experience of comparable events to refer to. Eyewitness reports, measurements carried out after the accident, and experimental reconstructions were necessary. The causes of the accident are still described as a fateful combination of human error and technological shortcomings.

The Causes: A Combination Of Reasons

The test during which the accident happened was carried out under time pressure. Shortly after it started, the test run was interrupted for nine hours. Electricity still had to be supplied to Kiev so the test took place at night.

Several flaws in the technical design of the RBMK are thought to have been decisive. These included the handling of the control rods. In a reactor, the power level is controlled by raising and lowering the control rods: raising the control rods increases power; lowering them absorbs more neutrons leading to a decrease in power.

In this type of reactor, however, the design of the control rods had a fatal flaw. Graphite followers fitted to the control rods could actually increase reactivity at the bottom of the core when the rods were inserted from a completely withdrawn position. Followers are a special design feature of the RBMK. They displace water and improve the reactor's neutron balance.

In the Chernobyl test, too many control rods were withdrawn and then simultaneously inserted into the core while the positive void coefficient was already causing a rapid rise in power. This caused the power level to rise so dramatically that the reactor was destroyed.

A similar error, but with much less severe consequences, had occurred in a reactor of the same type in Lithuania in 1983. This experience, however, was not passed on to the operating crew at Chernobyl.

Thirty-one people died as an immediate consequence of the accident; one in the explosion itself, one from coronary thrombosis, one from thermal burns and 28 from acute radiation poisoning. The highest radiation doses were received by the 1,000 on-site reactor staff and emergency workers on the first day of the accident. Among the more than 200,000 emergency and recovery operation workers exposed during the period from 1986 to 1987, an estimated 2,200 radiation-caused premature deaths must be expected during their lifetime.

Information on the individual received doses is sketchy, but doses are thought to have ranged from 170 millisieverts (mSv) in 1986 to 15mSv in 1989. A commonly used limit for the maximum allowable exposure is 1mSv per person per year above natural background levels. For comparison, average natural background radiation levels in the UK are 2.2mSv per person per year.

Nobody off-site suffered from acute radiation poisoning.

The Sequence Of Events Leading Up To the Accident

Reactor number four, an RBMK unit of 925 MW (electrical) is to be shut down for routine maintenance. It is decided to take advantage of the shut-down to run a test.

The test is to demonstrate that in the event of loss of power, a slowing turbine has enough inertial energy to power the reactor cooler pumps until emergency diesel generators cut in. The reactor's emergency cooling system is deliberately disabled so it doesn't cut in when the main pumps slow down.

Due to operational error, power falls to 30 MW thermal * – well below the designed test power of 700 to 1000 MW thermal – a level where the positive void coefficient is dominant.

The neutron absorbing fission product xenon builds up. This, together with a decrease in coolant flow, decreases reactivity, making it difficult for the operator to restore power rapidly.

The operator stabilises reactor power at 200 MW thermal, but is unable to raise power further due to shortage of reactivity. The operator decides to proceed with the test.

With reactor power reduced and eight pumps operating, water flow exceeds permitted levels. The extra water absorbs neutrons, reducing reactivity. In an attempt to compensate, the operator withdraws the control rods further.

The operator has difficulty manually maintaining the water level and steam pressure in the steam drums. He disconnects the protection system that would have tripped the reactor.

At one point, only eight control rods are used. Procedure stipulates at least 30 are needed to maintain control.

Operators allow the test to continue, despite knowing that insufficient reserve exists to shut down the reactor should an emergency develop.

The operator closes the steam supply to the turbo-generator to start the test. There is a sudden and unexpected power surge due to the positive void coefficient. Reactor power increases exponentially, up to an estimated 100 times nominal. The control rods cannot be re-inserted in time. The fuel overheats and some of the fuel channels rupture.

The resulting explosion blows the 1,000-tonne sealing cap on the reactor clear of the core. A second explosion throws out fragments of burning fuel and graphite from the core. Air rushes in to the exposed core, causing the graphite moderator to burst into flames.

* *Thermal power is the power produced by the uranium fission reaction in the form of heat in the reactor. This heat is used to make the coolant – water – boil. Water vapour is produced, transported to the turbines and makes them turn to produce electricity in the generator. Because of the funda-*

mental laws of physics, only about a third of the heat can be transformed into mechanical energy by turbines and then into electrical energy by the generator. The remainder is waste heat dissipated by the cooling tower or surface water. As a result, the thermal capacity of a nuclear power plant is about three times larger than the electrical capacity.

The Aftermath

With the reactor core now fully exposed, a plume of smoke, radioactive fission products and debris rose more than ten kilometres into the air.

The material was carried northwest by the wind, mainly to Belarus, although other areas were affected, including Ukraine.

Fires broke out all over the plant. About 250 firemen were called, many of whom were not equipped with measuring instruments to monitor the radiation dosages they were receiving. The operators and rescue workers are to be commended. Many stayed on call in the area after having been relieved of their duties and many risked their lives to save others and bring the situation under control.

Most of the fires had been extinguished by 05:00, but the graphite fire continued for another nine days. The main release of radioactivity into the environment was caused by the burning graphite.

On 27 April, the town of Pripyat, with about 45,000 inhabitants, was evacuated completely. The evacuees were never to return, and the town remains how it was left. In the years following the accident, a further 210,000 people were resettled into less contaminated areas, and the initial 30-kilometre radius exclusion zone (2,800 square kilometres) was extended to cover 4,300 square kilometres.

To put out the reactor fire and stop the release of radioactive materials, fire-fighters pumped cooling water into the core of the reactor during the first 10 hours after the accident. This unsuccessful attempt to put out the fire was then abandoned. From 27 April to 5 May, more than 30 military helicopters flew over the burning reactor. They dropped 2400 tonnes of lead and 1800 tonnes of sand to try to smother the fire and absorb the radiation.

These efforts were also unsuccessful. In fact, they made the situation worse because heat accumulated beneath the dumped materials. The temperature in the reactor rose again and thus also the quantity of radioactive products emerging from it. In the final phase of fire-fighting, the core of the reactor was cooled with nitrogen. Not until 6 May were the fire and radioactive emissions brought under control.

On 9 May, work began to dig a tunnel underneath the core to install a huge concrete slab and cooling system. The slab was intended to act as a barrier to prevent radioactive material leaking into the groundwater. Finally, the core was entombed in a 300,000-tonne concrete and steel shelter, or “sarcophagus”, and the surrounding land and buildings decontaminated.

It is estimated that about six tonnes of uranium dioxide fuel and solid fission products escaped, among them many radionuclides, as well as radionuclides – principally xenon, krypton, iodine, tellurium and caesium – in form of gases and small particles. It is estimated that about six tonnes of uranium dioxide fuel and solid fission products escaped. Many of them were highly radioactive. Moreover, radionuclides in the form of gases and small particles escaped – principally xenon, krypton, iodine, tellurium, and caesium.

According to the WHO, a total of about 12 exabequerels of radioactivity was released.

A becquerel – abbreviation Bq – is the activity of a quantity of radioactive material in which one nucleus decays per second. This is not much. One gram of the naturally occurring radioactive substance radium-226 has an activity of 37 gigabequerel (this quantity is called one curie, an older unit for radioactivity), and this is a significant amount. Twelve exabequerels are 12 trillion becquerels, a number with 20 digits (12 followed by 18 zeros) and would correspond to 300 tonnes of radium.

The highest levels of contamination were within a 30-kilometre radius of the site; levels of caesium-137 exceeded 1500 kilobequerels per square metre (kBq/m^2). Caesium-137 was used as an indicator because it is easily measurable, and posed the greatest health risk once another radioactive element released by the accident, iodine-131 (which has a short half-life of eight days) had decayed. Levels of 40 kBq/m^2 covered large parts of northern Ukraine and southern Belarus, with a number of "hot-spots" occurring where it happened to be raining as the cloud passed over.

The first time the cloud was detected outside of the USSR was by workers at a Swedish nuclear plant, who suspected another Swedish facility. The cloud was tracked and passed over Scandinavia, the Netherlands, Belgium and the UK, carried by easterly winds. It then went south, covering much of the rest of Europe, in particular Slovakia, Romania, Bulgaria, Greece and Turkey and then again Poland. As a result of changing wind and rainfall patterns, the distribution was locally very uneven[**].

Contamination was detected in nearly every country in the northern hemisphere, as far as North America and Japan, and half a year later also in the Southern Hemisphere. However, detection does not mean risk, because measuring methods are extremely sensitive and amounts can be easily detected that are many orders of magnitude below any risk level.

The Health Effects

The exact nature of the long-term health effects of the Chernobyl accident is impossible to define or predict. However, learned estimations of the upper limits of possible consequences are feasible (see also box text pages 21 and 22).

According to a United Nations report published in 2002, the number of thyroid cancer cases among people who were children and adolescents when the accident happened will reach 8000 in the coming decades. The IAEA says about 4000 cases of thyroid cancer, mainly in children and adolescents at the time of the accident, have resulted from the accident' s contamination and at least nine children died of thyroid cancer. However, the survival rate among such cancer victims, judging from experience in Belarus, has been almost 99%. There is a consensus that at least 1800 children and adolescents in the most severely contaminated areas of Belarus have contracted thyroid cancer because of the Chernobyl accident. Thyroid cancer is normally a treatable disease.

In September 2005, the Chernobyl Forum published a report (the Chernobyl Forum Report 2005), written by more than 100 specialists from seven UN organisations including the WHO, the IAEA and the World Bank, as well as from Belarus, Russia and Ukraine.

The report concludes that up to 4,000 people could eventually die prematurely of radiation exposure from the accident. It said public health effects have not been nearly as substantial as had at first been feared. By and large, scientists did not find serious negative health impacts on the general population in surrounding areas. Nor did they find widespread contami-

[**] An animated reconstruction of the cloud's path can be found on the website of France's Institut de Radioprotection et de Sûreté Nucléaire (IRSN): www.irsn.fr/FR/popup/Pages/tchernobyl_video_nuage.aspx

nation that would continue to pose a substantial threat to human health, except for a few exceptional, restricted areas.

The findings and conclusions of the Forum Report have essentially been confirmed in a follow-up report published by the United Nations Scientific Committee on Atomic Radiation (Unscear) published in February 2011.

As of end-2010, fewer than 50 deaths had been directly attributed to radiation from the disaster, almost all being highly exposed rescue workers, many of whom died within months of the accident, but others as late as 2004.

The Chernobyl Forum report said most emergency workers and people living in contaminated areas received relatively low whole-body radiation doses, comparable to natural background levels. As a consequence, no evidence or likelihood of decreased fertility has been found, nor has there been any evidence of increases in congenital malformations that can be attributed to radiation exposure. The report also said poverty, mental health problems and “lifestyle” diseases in the former Soviet Union pose a greater threat to local communities than radiation exposure.

The estimate for the eventual number of deaths in the Chernobyl Forum report is far lower than earlier speculation that radiation exposure would claim tens of thousands of lives.

In 1986, a WHO representative told a conference that claims by Ukrainian officials that more than 100,000 people had died as a result of the accident were “fiction”. He said the proven death toll was about 40; some due to direct exposure at the time, and a further 10 fatal cases of radiation-induced thyroid cancer.

A report published in 2000 by Unscear concluded that there was no evidence that most people exposed to radiation from Chernobyl in Ukraine or elsewhere were likely to suffer any serious long-term health effects. Unscear’s follow-up report of 2011 confirmed this conclusion. A 2002-United-Nations report on the human consequences of Chernobyl said “very considerable uncertainty remains” over the possible long-term health effects of the accident. It said morbidity in the affected areas continues to reflect the pattern in other parts of the former Soviet Union. Life expectancy, particularly of males, is substantially lower than in western and southern Europe, with heart disease and trauma the leading causes of death.

The report said no reliable evidence has emerged of an increase in leukaemias, which had been predicted to result from the accident. However, it said some 2,000 cases of thyroid cancer have so far been diagnosed among young people exposed to radioactive iodine in April and May 1986.

There have been reports of some thousands of deaths among clean-up workers since the accident.

These reports are difficult to evaluate for a number of reasons. First, it has proved difficult to trace the workers because they were so many and have returned to areas all over the former Soviet Union. Second, any normal population would have sustained deaths naturally in any 20-year period. (For example, in developed countries, the normal death rate is about 0.3% per year, or about 36,000 deaths in a population of 600,000 over a 20-year period). Third, many of the diseases being claimed among the clean-up workers, such as heart disease, have been shown not to be caused by radiation.

In the areas of Belarus, Russia and Ukraine defined as "contaminated areas" by the former Soviet Union, because of higher soil levels of the long-lived caesium-137, the average additional dose over the period 1986-2005 is "approximately equivalent to that from a medical computed tomography scan".

The report also says that it is not possible to state scientifically that radiation caused a particular cancer in an individual. This means that in terms of specific individuals, it is impossible to determine whether their cancers are due to the effects of radiation or to other causes, or moreover, whether they are due to the accident or background radiation.

Chernobyl Today: Status In Brief

- While the detailed design for the New Safe Confinement is being finalised, work on the foundations has already started.
- Work on the structure will begin as soon as the design receives regulatory approval from the Ukrainian authorities, expected in late 2011.
- Overall cost of Shelter Implementation Plan (SIP) is close to €1.6 billion.

December 2000: Plant Closure

Safety concerns and operating problems led the international community to call for complete and permanent closure of the Chernobyl plant. The last operating reactor of the four at Chernobyl was permanently shut down on 15 December 2000.

In December 1995, Ukraine signed a memorandum of understanding with the G7 (now the G8) countries and the European Union on the closure of the then operating units at Chernobyl. This followed an acceleration of international cooperation after the collapse of the Soviet Union. The major task was to assess the risks posed by the destroyed reactor and to devise a strategy to provide a long-term solution for remediation of the site. The G7 countries and the EU took the lead in helping Ukraine find a solution to the risks posed by the destroyed unit four.

In 1996, the Chernobyl Centre for Nuclear Safety, Radioactive Waste and Radioecology was established in Slavutich. The centre provides engineering, scientific and technical services in the fields of nuclear and radiation safety, decommissioning, emergency response and radioecology. The centre's International Radioecology Laboratory (IRL) is carrying out research within the 30-kilometre Chernobyl exclusion zone. This research includes studying the impact of radioactivity on animal cells and tissue.

Steps have been taken to upgrade the unstable shelter that was hastily built in 1986 around the destroyed reactor number four. That shelter – the "sarcophagus" – covers the remains of the destroyed unit four and new structures and systems built after the accident. Corrosion and other factors have increased the risk of its collapse.

In June 1997, Ukraine, the G7 (as it was then) and the EU approved the Shelter Implementation Plan (SIP), which now covers both the stabilisation of the "sarcophagus" and construction of the New Safe Containment (NSC). This is a more secure and permanent structure to be built around the sarcophagus. The stabilisation project ended successfully in 2008.

Construction of the NSC is an unparalleled project in the history of engineering. With a height of more than 100 metres it will be big enough to house the Statue of Liberty. The new structure will be assembled on site, but away from the highly radioactive unit 4 and then slid in place, covering the remains of the reactor building and the old shelter. It has a design lifetime of 100 years.

The G8 nations pledged to contribute US$300 million towards the Chernobyl Shelter Fund (CSF), which was set up in 1997 to administer contributions towards the cost of stabilisation work on the sarcophagus and construction of the NSC. The fund is managed by the EBRD.

Ukraine is cooperating with the countries of the G8 economic group, Russia, and the European Commission in activities to stabilise and maintain the sarcophagus, to build the NSC, and to remove portions of the existing shelter to ensure its long-term stability.

The sarcophagus still contains radioactive material. The inventory includes more than 200 tonnes of uranium and around one tonne of radionuclides, of which 80% is plutonium.

Next Steps

The Shelter/NSC

- Build the New Safe Confinement;
- Once the New Safe Confinement is complete, remove unstable sarcophagus structures.

Decommissioning

- Remove fuel from reactors 1-3 and complete radioactive waste facilities.

The Costs

According to the EBRD, the overall cost of the SIP including support to the regulatory authorities as well as project and fund management is close to €1.6 billion. It still requires an additional €600 million. The overall cost of construction of the Interim Storage Facility (ISF-2) is close to €300 million, with €140 million still needed.

Considerable contributions have been made to both funds. After an initial pledge of US$300 million at the G7 summit in Denver 1997 for the Chernobyl Shelter Fund, two pledging conferences took place in November 1997 (New York) and May 2000 (Berlin) followed by another in 2005 (London).

A separate pledging event was held in 2008 to raise additional funds for the Nuclear Safety Account (NSA). Contributors to the EBRD-managed NSA have agreed to finance the construction of two facilities needed to prepare the plant for the decommissioning, one to safely store the spent fuel from the operations of the Chernobyl nuclear power plant and one to treat liquid radioactive waste.

Preparations are under way for a pledging event in Kiev in April 2011 to coincide with the 25th anniversary of the accident.

Chernobyl Shelter Fund Contributions	
Donor	**Contribution (€ million)**
European Community	250.0
United States	182.8
Germany	60.5
United Kingdom	53.1
France	52.5
Japan	45.7
Ukraine	45.0*
Italy	41.5
Canada	34.9
Russia	15.3
Switzerland	9.3
Ireland	8.0
Austria	7.5
Sweden	7.2
Norway	7.0
Netherlands	5.7
Kuwait	5.4
Spain	5.1
Denmark	5.0
Greece	5.0
Finland	4.9
Belgium	4.3
Poland	2.5
Luxembourg	2.5
** In addition, Ukraine has agreed to take over one SIP task valued at US$22 million.*	

Nuclear Safety Account Contributions	
Donor	**Contribution (€ million)**
France	63.3
United Kingdom	40.4
Germany	37.5
European Community	36.2
Japan	27.0
United States	26.3
Italy	21.2
Canada	15.3
Switzerland	10.9
Sweden	9.0
Russia	7.6
Finland	6.0
Ukraine	5.8
Netherlands	4.2
Denmark	63.3
Norway	40.4
Belgium	37.5
France	36.2
United Kingdom	27.0
Germany	26.3
European Community	21.2
Japan	15.3
United States	10.9
Italy	9.0

The Future

Twenty-five years after the accident at Chernobyl, two crucial projects are entering the completion phase: The construction of the NSC for the destroyed reactor 4 is about to begin and a storage facility for spent fuel from the operations of reactors 1-3 can now be finalised after the Ukrainian regulator has approved the project design.

However, at this stage, funding for the two projects is not yet fully secured. According to the EBRD, €740 million in additional financing still needs to be raised.

The initial clean-up operation at Chernobyl was impressive. The sarcophagus was completed in only seven months and radiation levels on the site are now relatively low.

But decommissioning the three remaining reactors first required an infrastructure, including:

- A new heating plant, completed in 2001. This consists of three hot water boilers of 50 megawatt thermal (MWt) each and three steam boilers of 40 MWt each. The plant has sufficient capacity to power a city and will be able to meet all anticipated future site demand including that of the decommissioning infrastructure.
- A new interim spent fuel store (ISF-2) because the existing store was inadequate.
- A new liquid radioactive waste storage facility, which is substantially complete, to treat low- and medium-level liquid radioactive waste accumulated during the reactors' operational lifetimes. About 25,000 cubic metres of this waste is currently stored in tanks on-site. The new facility will receive, process (i.e. reduce the volume), encapsulate and dispatch the waste to a repository.
- A solid radioactive waste treatment plant, construction of which has begun.

The new interim spent fuel store, or ISF-2, is needed so fuel can be removed from the reactors. There was not enough existing capacity for this. Design issues caused construction of ISF-2 to be halted in 2003 while solutions were sought. In the meantime, removal of some of the fuel from reactors 1-3 to the existing storage facility began in December 2005.

A conceptual design and a concept design safety document for the NSC have already been approved. The concept shows an arch-shape structure with a height of more than 100 metres and an internal span of 245 metres. The structure will be 150 metres long and its end walls will be built around the existing sarcophagus.

The contract for design and construction of the NSC was signed in September 2007 with the Novarka consortium, formed by the construction companies Bouygues and Vinci.

Work on the detailed design of the structure and its systems such as cranes, fire protection, and ventilation is complete and regulatory approval is expected in 2011. The assembly site has been cleared and excavation work for the foundations has been completed. Piling for the foundations and the lifting cranes started in September 2010.

Slavutich

On 27 April, 36 hours after the accident, the 45,000 inhabitants of the town of Pripyat, four kilometres from the plant, were evacuated in buses. The town remains uninhabited to this day.

In the period up to 5 May, people living within a radius of 30 kilometres of the reactor had to leave their homes. Within 10 days, 130,000 people from 76 settlements in this area were evacuated.

Before the accident, the Chernobyl workforce and their families lived in the town of Pripyat, close to the plant. Within 48 hours, they had been evacuated from their homes and now live in a new town called Slavutich (also Slavutych), 50 kilometres east of the plant.

The town was built by eight former Soviet republics: Estonia, Latvia, Lithuania, Belarus, Azerbaijan, Armenia, Russia and Ukraine. Each republic brought its own workforce and materials, and built houses and apartments in its own style. Therefore, the town had eight different sectors, each very different in architectural style and atmosphere.

The population of Slavutich today is about 25,000. About one third of the population is under the age of 16. About 3000 residents work at the Chernobyl site, mostly on monitoring and maintenance. In 2011, 500 to 700 of them were working on construction of the various waste storage facilities and preparing the ground for the New Safe Confinement (NSC).

The town has Ukraine's youngest population, highest birth rate and lowest mortality rate. The families of Slavutich enjoy a relatively high standard of living and have access to some of the best stocked shops in Ukraine. There are also schools, sports facilities, and one of the country's best hospitals.

With the closure of Chernobyl as a power plant in 2000, the town had to come to terms with the socio-economic problems of adapting to being less dependent on the plant. The town administration, supported by international agencies, has made progress with the establishment of a business development agency, business incubator, centre for community development, credit unions, and facilities to encourage enterprise and attract new business.

The International Labour Organisation created a training centre in Slavutich where former Chernobyl plant employees are being retrained for other jobs. In 2002, the United Nations Development Programme earmarked US$597,000 for further training programmes of this kind.

Environment

The plume of radioactive fission products from the destroyed reactor dropped fall-out over most of Europe in a complex pattern mainly in May 1986.

The accident resulted in the radioactive contamination of 18,000 square kilometres of agricultural land, of which 2640 square kilometres could no longer be farmed. In Ukraine, the forest was particularly affected: 35,000 square kilometres of forested areas, 40% of the total, were contaminated. In the forests, the conifers and broadleaves absorbed the radiation like a filter, and the fallout was initially concentrated here. Dead leaves and needles have since transported the contamination into the soil. In the coming decades, the contamination will accumulate in wood.

The radioisotope caesium-137 was a significant problem. Its 30-year half-life means half of its activity will still be in the environment in 2016 and a quarter in 2046. Caesium is chemically similar to the nutrient potassium, so tends to be taken up readily by plants and animals and enter into the food chain. As it rises up the food chain, its concentrations can become higher in specific foodstuffs.

The main routes into the food chain are from consumption of contaminated berries, mushrooms, game and fish, and via grass and hay eaten by dairy cattle. It is estimated that concentrations in fish in Lake Kozhanovskoe, Russia, will remain above the recommended maximum limit for consumption for another 30 years.

Milk contaminated with a radioactive isotope of iodine (I-131, 8-day half-life) in the weeks after the accident in Soviet areas (today: Belarus, western and southern oblasts of Russia, and Ukraine) is believed to be responsible for cases of thyroid cancer. Quantities of potentially contaminated milk in Poland, Hungary, Austria and Sweden were destroyed.

Many countries across Europe burned contaminated vegetation, and a ban on many agricultural goods was placed across Eastern Europe. Among the worst affected were Sweden's and Finland's reindeer and sheep.

The sale of milk, meat, many fruit and vegetables was banned in 1986 and 1987 in the markets of Kiev, Chernigov, Minsk, and other smaller cities and towns. In the UK, Ministry of Agriculture restrictions on the sale and slaughter of sheep lasted for only a few months after the accident.

The degree of soil contamination in Belarus, Russia and Ukraine was influenced by several factors: the natural decay process of the radioactive isotopes, their mobility in the earth, and the type of soil. For example, in Belarus, which received 70% of the fallout, about 22% of the country was declared contaminated with more than 1 curie of caesium-137 per square kilometre (or 37 kBq/m^2) after the accident in 1986.

The Belarusian government's Chernobyl Committee estimates that 16% of the territory will still be contaminated in 2016.

The OECD Nuclear Energy Agency has said that since the accident, the dose rate from external radiation has decreased by a factor of 40 in some areas and in some places is less than 1% of its original value. In short, there is a continuous, but slow, reduction in the levels of caesium-137 activity in agricultural soil.

Forest fires in contaminated areas of western Russia and Ukraine in July and August 2010 resulted in a transitional elevation of contamination in the air. However, the radioactivity levels (in particular, of caesium-137) were many orders of magnitude lower than in 1986 and no supplementary protection measures were necessary.

The situation regarding contamination of food can be expected to continue for some time to come. As far as agricultural production is concerned, the central problem is the small farmers, who often live off their own produce. Both the official Belarusian Chernobyl Committee and the Ukrainian government agency Chernobyl Interinform have established aid programmes to include special efforts to improve advisory services for these subsistence farmers.

Radiation And Animals

Since 1994, Dr Robert J. Baker and Professor Ronald K. Chesser, together with colleagues in the Ukraine and the UK, have worked extensively examining the effects of radiation on animals surrounding Chernobyl. Dr Baker and Prof Chesser both work at Texas Tech University in the US.

They concluded that the elimination of human activities such as farming, ranching, hunting and logging have benefited wildlife. "It can be said that the world's worst nuclear power plant disaster is not as destructive to wildlife populations as are normal human activities," said Dr Baker.

Following research expeditions to the Chernobyl region, a US Department of Energy official asked Dr Baker to assess the ecological impact of the disaster on populations of animals.

Although a quantitative assessment was difficult, the net ecological impact was positive. But Dr Baker also said detailed long-term studies are needed to understand how animal populations exposed to chronic radiation differ from unexposed populations. Issues concerning the latent and long-term effects of exposure must be resolved before the total significance of the accident to native wildlife and to humans can be understood.

For more information:
www.nsrl.ttu.edu/chornobyl/conclusions.htm and
www.groenerekenkamer.nl/grkfiles/images/Chesser%20Baker%2006%20Chernobyl.pdf

All three countries have specified safe limit values for food from state farms and for goods that are to be sold in markets. In Belarus, for example, these limits are three times as stringent as the corresponding German regulations.

The efforts required to maintain this monitoring can be illustrated by the example of Ukraine. In 2000 alone, more than one million food samples were analysed nationwide, and the programme continues 25 years after the accident.

Since 1993, according to Chernobyl Interinform's figures for Ukraine, compliance with the official limits has been assured for produce from state-run farms and goods sold in public shops.

One of the main concerns immediately following the accident was the waters of the river Dnieper and its tributary, the Pripyat. Although the river did indeed distribute contamination throughout Ukraine, mitigation efforts were successful and drinking water was largely unaffected. Nevertheless, contamination has accumulated in other water basins, and there is still long-term a risk of groundwater contamination from strontium and americium.

With the exception of areas inside the exclusion zone, the air in the contaminated territories is no longer affected.

Nuclear Safety

There have been three major reactor accidents in the history of civil nuclear power: Three Mile Island in the US, Chernobyl in the ex-USSR, and Fukushima-Daiichi in Japan. The first one was contained, in the second one containment helped keep the impact on environment low, and the third one – Chernobyl – had no provision for containment.

These are the only major accidents to have occurred in some 14,000 cumulative reactor-years of commercial operation in 32 countries (data of 2010).

The risks from nuclear power plants, in terms of the likelihood and consequences of an accident or terrorist attack, are minimal compared with other commonly accepted risks. Nuclear power plants are robust. The goal of safety measures is to ensure that under all reasonably conceivable conditions public health and safety are never endangered by exposure to radioactivity.

The IAEA was set up by the United Nations in 1957 with one of its functions to act as auditor of world nuclear safety and security. It prescribes safety procedures and oversees the reporting of even minor incidents (see also box page 23: International Nuclear Event and Radiological Scale).

Its role has been strengthened in the last decade. Every country which operates nuclear power plants has an independent nuclear safety inspectorate and all of those inspectorates work closely with the IAEA.

Personal safety is among prime concerns for those working in nuclear plants. Radiation doses are controlled in a number of ways, including physical shielding, protective clothing and apparatus, limiting the time workers spend in areas with significant radiation levels, and by using remote handling techniques.

These are supported by continuous monitoring of individual doses and of the work environment to ensure very low radiation exposure comparable with other industries.

One mandated safety indicator to minimise the possibility of reactor accidents is the calculated frequency of degraded core or core melt accidents. The US Nuclear Regulatory Commission (NRC) specifies that reactor designs must meet a one in 10,000 year core damage frequency. Modern designs exceed this. The best currently operating plants are about one in one million and those likely to be built in the next decade – the so-called Generation III reactor types – are almost one in 10 million. The Three Mile Island accident in 1979 was the only accident in a reactor conforming to NRC safety criteria, and it was contained as designed without radiological harm to anyone. (The accident at Fukushima-Daiichi in Japan in March 2011 cannot yet be classified.)

Regulatory requirements today are that the effects of a core-melt accident must be confined to the plant, without the need to evacuate nearby residents.

The main safety concern has always been the possibility of an uncontrolled release of radioactive material, leading to contamination and consequent radiation exposure off-site. At Chernobyl, this happened and the results were severe, once and for all vindicating the extra expense involved in designing to high safety standards.

To achieve optimum safety, nuclear plants today operate using a “defence in depth” approach, with multiple safety systems. Key aspects of the approach are:

- High-quality design and construction;
- Equipment which prevents operational disturbances developing into problems;
- Redundant and diverse systems to detect problems, control damage to the fuel and prevent significant radioactive releases;

- Provisions to confine the effects of severe fuel damage to the plant itself.

The safety systems include a series of physical barriers between the radioactive reactor core and the environment, the provision of multiple safety systems, each with backup and designed to accommodate human error. Safety systems account for about one quarter of the capital cost of such reactors.

Safety systems include control rods, which are inserted to absorb neutrons, and secondary shut-down features that introduce neutron-absorbing material into the reactor. Back-up cooling systems remove excess heat.

In addition, most of the world's operating reactors – those at Chernobyl were an exception – have negative void coefficients. This means circulating water acts as both moderator and coolant. Both functions are needed to operate a fission reactor: moderation slows down the neutrons necessary to sustain the nuclear chain reaction and cooling carries away the heat energy released by the chain reaction. When the coolant liquid starts to boil and form steam bubbles – or when it leaks out due to a technical problem – voids are formed in the cooling liquid. This ultimately results in a reduction in power.

But not so at Chernobyl, where the reactors had a separate moderator made of graphite. With voids forming in the reactor cooling water channels, graphite moderation would continue and the chain reaction – instead of breaking down – would increase. In other words, the voids have a positive impact on the chain reaction. The result is a power surge.

There are other physical features that enhance safety. In the most common reactors, the fuel is in the form of solid ceramic pellets, and radioactive fission products remain bound inside these pellets as the fuel is burned. The pellets are packed inside zirconium alloy tubes to form fuel rods. These are confined inside a large steel pressure vessel with walls about 20 centimetres thick. This pressure vessel, in turn, is enclosed inside a robust concrete containment structure with walls at least one metre thick, protecting the installation against external attacks such as an aircraft crash.

Modern nuclear power plants are also designed with a high standard of seismic resistance and can be shut down safely and rapidly in the event of an earthquake. This happened in Japan on 16 July 2007 at the world's biggest nuclear power station, Kashiwazaki-Kariwa, and again in Japan on 11 March 2011, the reactors at Fukushima-Daini, Fukushima-Daiichi, Onagawa and Tokai-mura. With the exception of four reactor units at Fukushima-Daiichi, all the units of these plants resisted a tsunami as well. It followed the 9.0-magnitude earthquake and was about two times stronger than plants had been designed for.

The Three Mile Island accident of 1979 demonstrated the pertinence of the multiple safety-barrier concept. The containment building which housed the reactor prevented any significant release of radioactivity, despite the fact that about half of the reactor core melted inside the pressure vessel. The accident was attributed to a combination of mechanical failure, a maintenance error, and operator confusion. The reactor's other protection systems also functioned as designed. What's more, the emergency core cooling system would have prevented the accident, but the operators shut it down.

Investigations following the accident led to a new focus on the human factors in nuclear safety. No major design changes were called for in western reactors, but controls and instrumentation were improved and operator training and instructions were completely overhauled. By way of contrast, the Chernobyl reactor did not have a containment structure like those used in the West or in post-1980 Soviet designs.

Three Mile Island

The accident at unit 2 of the Three Mile Island nuclear power plant near Middletown, Pennsylvania, on 28 March 1979, was the most serious in US commercial nuclear power plant operating history, even though it led to no deaths or injuries to plant workers or members of the nearby community. But it brought about sweeping changes involving emergency response planning, reactor operator training, human factors engineering, radiation protection, and many other areas of nuclear power plant operations.

According to the US Nuclear Regulatory Commission, the sequence of certain events – equipment malfunctions, design-related problems and worker errors – led to a partial meltdown of the reactor core, but only very small offsite releases of radioactivity.

For the NRC's Backgrounder on Three Mile Island see www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html

In the immediate aftermath of Chernobyl, the IAEA gave high priority to addressing the safety of nuclear power plants, especially in some areas of eastern Europe, where deficiencies remained.

International programmes of assistance have been carried out by organisations such as the OECD's Nuclear Energy Agency, the IAEA, the Commission of the European Union and the EBRD-administered Nuclear Safety Account to enhance the safety of early Soviet-designed reactors by applying western safety standards, or implementing significant improvements to the plants and their operation.

Modifications have been made to overcome deficiencies in the RBMK reactors still operating in Russia. Among other things, these modifications have reduced the danger of a positive void coefficient response.

Since the World Trade Centre attacks in New York in 2001, there has been concern about the consequences of a large aircraft being used to attack a nuclear facility with the purpose of releasing radioactive materials. Various studies have looked at the possibility of such attacks on nuclear power plants.

The studies show that nuclear reactors would be more resistant to such attacks than virtually any other civil installation. A study was undertaken by the US Electric Power Research Institute using specialist consultants and paid for by the US Department of Energy. It concluded that US reactor structures "are robust and [would] protect the fuel from impacts of large commercial aircraft".

Similarly, the massive structures mean that any terrorist attack even inside a plant would not result in any significant radioactive releases.

March 2011: Fukushima-Daiichi

It is too early to say what the repercussions of the accident at the Fukushima-Daiichi nuclear plant in Japan in March 2011 will be for the nuclear industry.

Safety authorities in many countries with nuclear programmes have called for reviews of their nuclear plants. In Europe, the EC is calling for stress tests to be carried out to make sure plants would be able to withstand the impact of earthquakes and tsunamis or floods.

What is clear is that Fukushima-Daiichi, which has six reactor units, withstood the impact of the earthquake.

But problems arose because electricity rooms and seawater pump rooms were flooded when the tsunami struck. External power supply was interrupted and all but one of the emergency diesel generators stopped due to tsunami damage.

The extended loss of all cooling functions resulted in fuel damage in the reactor cores of units 1, 2, and 3 and in the spent fuel pools of units 1 to 4.

Overheating and damage to fuel elements resulted in loss of containment, damage to buildings and installations, and the release of radioactive substances into the environment, with high dose rates at the plant site and beyond its boundary.

The Japanese government decided to evacuate people living in a 20-kilometre zone around the plant and advised people within a 30-kilometre zone to stay indoors

The events have been provisionally rated at Level 5 on the International Atomic Energy Agency's International Nuclear and Radiological Event Scale (INES).

Level 5 on the scale means an "accident with wider consequences".

Chernobyl was Level 7 of the scale, meaning "major accident".

See INES boxed text page 24.

The Health Effects of Chernobyl: As Reported By NucNet

On 5 September 2005, under the headline *Chernobyl Health Effects 'Not As Substantial As Feared'* NucNet reported the findings of the Chernobyl Forum report:

Up to 4000 people could eventually die of radiation exposure from the Chernobyl nuclear power plant accident nearly 20 years ago, an international team of more than 100 scientists has concluded.

But the scientists said public health effects have not been nearly as substantial as had at first been feared.

By and large they did not find serious negative health impacts on the general population in surrounding areas. Nor did they find widespread contamination that would continue to pose a substantial threat to human health, except for a few exceptional, restricted areas.

As of mid-2005, fewer than 50 deaths had been directly attributed to radiation from the 1986 disaster, almost all being highly exposed rescue workers, many who died within months of the accident but others who died as late as 2004.

The estimate for the eventual number of deaths is far lower than earlier speculation that radiation exposure would claim tens of thousands of lives.

On 3 March 2011, under the headline *New UN Chernobyl Health Report 'Reconfirms Earlier Findings'* NucNet reported the following:

Major conclusions regarding the scale and nature of the health consequences of the 1986 Chernobyl nuclear accident are "essentially consistent with previous assessments", the United Nations Scientific Committee on the Effects of Atomic Radiation (Unscear) says.

The 173-page report, 'Health effects due to radiation from the Chernobyl accident,' reconfirms that radiation doses to the general public in the three most affected countries were relatively low and most residents "need not live in fear of serious health consequences".

Among the report's major findings are:

- 134 plant staff and emergency workers suffered acute radiation syndrome (ARS) from high doses of radiation;
- In the first few months after the accident, 28 of them died;
- Although another 19 ARS survivors had died by 2006, those deaths had different causes not usually associated with radiation exposure;
- Skin injuries and radiation-related cataracts were among the most common consequences in ARS survivors.

Energy Industry Study Shows 'Far Fewer Fatalities' In Nuclear Sector

The nuclear energy industry is perceived as high risk, but comparison with other energy sources shows "far fewer fatalities", according to a 2010 study by the OECD's Nuclear Energy Agency.

The study, primarily directed at policymakers, used data gathered by the Paul Scherrer Institute (PSI) in Switzerland. The data consists of accidents that have caused five or more "prompt fatalities" from 1969 onwards. The study considered the "full energy chain" from exploration and extraction to waste treatment and disposal. It looked at severe accidents, which it defines as accidents that result in five or more prompt fatalities.

The study concluded that, contrary to the expectations of many people, nuclear power generation presents "a very low risk" in comparison to the use of fossil fuels.

PSI's database contains data on 1,870 severe energy related accidents. It shows that from 1969 to 2000 there were 81,258 immediate fatalities across all energy chains. There were 1,221 severe accidents in the coal industry, but only one – Chernobyl – in the nuclear industry. In OECD countries there has never been a severe accident at a nuclear power plant. The worst energy related accident was the Banqiao/Shimantan dam failure in China in 1975 when some 30,000 people were killed.

The study is online:
www.oecd-nea.org/ndd/reports/2010/nea6861-comparing-risks.pdf

The International Nuclear and Radiological Event Scale

The International Nuclear and Radiological Event Scale (INES) was developed by the IAEA and the OECD in 1990 to communicate and standardise the reporting of nuclear incidents or accidents to the public.

The INES Scale explains the significance of events from a range of activities, including industrial and medical use of radiation sources, operations at nuclear facilities and transport of radioactive material.

Events are classified on the scale at seven levels: Levels 1 to 3 are called "incidents" and Levels 4 to 7 "accidents". The scale is designed so that the severity of an event is about 10 times greater for each increase in level on the scale. Events without safety significance are called "deviations" and are classified Below Scale / Level 0.

Chernobyl rated as 7 (Major Accident) on the scale and Three Mile Island rated 5 (Accident with Wider Consequences). A level 4 "Accident with Local Consequences" occurred in France in 1980. Another accident rated at level 4 occurred in a fuel reprocessing plant in Japan in September 1999.

7 Major Accident (Chernobyl)
6 Serious Accident
5 Accident with Wider Consequences
4 Accident with Local Consequences
3 Serious Incident
2 Incident
1 Anomaly
0 Below Scale / No Safety Significance